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Abstract

In this report, we discuss the role and the impact that the Internet has had on logistics. Two major types of impacts are examined: the possibility to integrate a company into a supply chain and, more generally, into the complex network of suppliers, partners, intermediaries, and customers it belongs to, and the capability of using the Internet for electronic business, a type of use that is deeply modifying the way sellers and buyers interact. The role of operations research based methodologies to empower electronic logistics and value chain management is also examined. An actual e-marketplace application illustrates the topic.

Keywords: Logistics, value chain management, electronic business, electronic marketplaces, Internet.

Résumé

Nous examinons dans ce rapport le rôle et l'impact d'Internet sur la logistique. Deux rôles majeurs sont traités en particulier : la possibilité d'intégration d'une firme dans une chaîne de valeur ou, de façon plus générale, dans le réseau de ses fournisseurs, partenaires, intermédiaires et clients, ainsi que les perspectives offertes par Internet dans l'utilisation des affaires électroniques, utilisation qui modifie significativement les interactions entre vendeurs et acheteurs. Le rôle de la recherche opérationnelle dans la logistique électronique et la gestion des chaînes de valeur est également discuté. Une application dans le domaine des marchés électroniques illustre le propos.

Mots-clés : Logistique, gestion de la chaîne de valeur, affaires électroniques, marchés électroniques, Internet.

I. Role of the Internet in Logistics

The beginning of electronic exchanges may be traced back to the 1970's. Exchanges were limited at that time to monetary transfers among a number of large firms and financial institutions. The 1980's saw the introduction of *Electronic Data Interchange* (*EDI*) systems that targeted the traffic of orders, waybills, invoices, and so on, with the promise of a significant reduction in paperwork and associated costs. EDI was embraced by large firms, particularly in the manufacturing and transportation sectors, and their suppliers, distributors and other partners did not really have another choice but to follow. These early efforts were marred by inter-operability issues at the level of the communication hardware and software, which translated in high investment costs for firms that needed to exchange with partners using different systems.

A number of other systems based on electronic exchanges were also introduced during this period. Most were designed for utilization restricted to particular communities and quite independent of other electronic-exchange systems. Trading systems for traders on stock markets and airline-reservation systems for travel agents and airlines are two such examples. In the transportation sector, *Intelligent Vehicle-Highway Systems* (*IVHS*) were aimed at a larger audience, agencies monitoring and controlling traffic in major cities and intercity-corridors and the people driving their automobiles on these roads, but were still ignoring large pans of the industry and the public, as well as the EDI systems motor carriers could have had. These systems evolved significantly during the 1990's and the beginning of the third millennium toward more open and integrated systems. More and more sophisticated and integrated information systems have impacted the organization of all companies, starting from the large ones and progressively involving the SMEs (Small and Medium Enterprises). For example, reservation systems are now targeting the entire travel and leisure industry, bringing potential customers directly in contact with potential service providers. IVHS have similarly evolved into *Intelligent Transportation Systems* (*ITS*) for all transportation modes and users, for passenger and freight transportation over all ranges of distances. This evolution and integration, far from being over, continue today, supported by the continuous evolution of electronic devices. It paralleled the evolution of the business community from the *electronic commerce* (e-commerce) concept to the *electronic business* (e-business) paradigm. The whole range of these systems makes up the so-called electronic society.

In this chapter we discuss the role and the impact that the *Internet* has had on logistics (see also Chopra and Meindl, 2004; Shapiro, 2001; Simchi-Levi, Kaminski, and Simchi-Levi, 2003). In fact, we will refer as often to supply or value chain management as to logistics since the terms are increasingly referring to the same concepts. Traditionally, and particularly in North America, the two terms designated two different points on view. Logistics used to deal with the planning and control of material flows and related information within a company, often restricted to the management of inventory and distribution activities. The concept of supply chain management has been developed coming from two different perspectives, the purchasing and supply management and the transportation and logistics management. It claimed a more comprehensive view of the firm activities and its linkages with partner organizations to ensure timely procurement and availability of materials for the firm as well as the production and delivery of services and goods to customers. The utilization of the term "value chain" is meant to emphasize the goal of this global management to produce value for all participants involved in the chain. The increased utilization of the Internet, electronic data exchanges, and electronic transactions has added new meaning and power to the value-chain concept and has brought logistics to adopt essentially the same holistic view of the relations of the firm with its upstream and downstream partners. This evolution is marked by the in-

troduction of the term "logistics management" and the transformation of the *US Council of Logistics* into the *US Council of Supply Chain Management Professionals*.

The first major type of impact Internet has had on logistics is thus related to the possibility to integrate a company into a supply chain and, more generally, into the complex network of suppliers, partners, intermediaries, and customers the company belongs to. This has been made possible by means of typically Internet-based integrated information systems. Thanks to such systems, a more global view of logistics has become possible and, together with a more global view, a more global optimization of the system has become possible. The second major type of impact is related to the possibility of using the Internet for electronic business, a type of use that is deeply modifying the way sellers and buyers interact.

While, at least in principle, the first type of impact has influenced the organization and the management of companies, it did not influence their suppliers and customers. It "simply" improved the efficiency and effectiveness of the supply chain. On the contrary, the second type of impact did modify the interactions between buyers and sellers, not only in terms of type and quality of the interactions but also in terms of selection of the suppliers and contacts with the customers.

It is also worthy to note that Operations Research-based methodologies empower electronic logistics and value chain management. Indeed, while Information Technologies provide the means to timely and accurately exchange information, Operations Research provides the means to transform this raw data into meaningful information and decisions. The following sections illustrate these concepts.

II. Internet-based Information Systems

We briefly discuss here the evolution of information systems up to the advanced phase that includes Internet-based systems under the light of the impact that such systems have had on logistics and supply chain management. Companies have enhanced over the years their efficiency and effectiveness by streamlining and improving their internal operations, from procurement to warehousing, from production to distribution. Today's global competition has imposed not only a continuous re-assessment of internal processes but also a continuous enhancement of the efficiency and effectiveness of relations with external companies to ensure one's competitive place on the market. The objective of reducing costs while improving the service level can only be reached by a global optimization of the supply chain and a constant control of uncertainties.

The development of *Inter-Organizational Information Systems* (*IOS*) can be categorized in four phases (Shore, 2001; Williamson, Harrison, and Jordan, 2004). In phase one, information technology did not contribute significantly to the information system. In phase two, the development of EDI had a tremendous impact on the automation of information flows. Many transactions, such as those related to ordering and invoicing, could be processed through EDI. The need of a Value Added Network (VAN), however, reduced the flexibility of suppliers that were connected to more than one customer because they needed to support different technologies. The number of EDI standards grew dramatically but currently universal standards allow companies to exchange data seamlessly between their computer systems. The phase three is characterized by more integration. The so-called *Enterprise Resource Planning* (*ERP*) systems are the result of the evolution of *Manufacturing Resource Planning (MRPII)* systems. Although ERP systems allow integration of companies with their suppliers and customers through an integrated database system, these systems were de-

signed to integrate the various functions of an individual company. Moreover, their architecture is typically closed. Phase four is thus based on the development of web technologies, such as XML and Java, that enable the integration of the information system of a company with those of its strategic partners. Two-ways information flows improve quantity and quality of communication, reduce costs and times and increase satisfaction of all partners.

Obviously, moving from a phase to a successive one is costly for a company in financial terms but even more in terms of the enormous impact such a move has on the organization culture and operations as well as on the business processes and relations. A limited number of companies have adopted an integrated system. The variety of individual information systems represents a major obstacle to the foreseen integration. Technologies represent the enabling mean to reach the proper level of communication in supply chain management, but are useless or may even have a negative impact on the business if not properly chosen, used and governed by managers.

The systems of phase four make it possible to a company the accomplishment of a variety of important goals that can be summarized in the following four (Simchi-Levy, Kaminski, and Simchi-Levi, 2003): 1) Collect information and make it available to all parties involved in the supply chain; 2) Access any data from a single point of contact; 3) Plan activities based on information from the entire supply chain; 4) Collaborate with partners.

Good logistics and supply chain management are made up of information and decision technologies. Information must display a number of fundamental characteristics to be useful when making decisions. Information must be accurate and accessible in due time. Delays may make information useless or even negative. Information must be of the right kind. Since information is costly, it is essential that valuable information be collected while useless information is avoided. The first of these four characteristics allows partners to be aware of the situation through reliable and timely information. When delays are drastically cut to the minimum, the efficiency of decision-support technologies is enhanced and better and more timely decisions can be taken.

The second goal, the single point of contact, means that information is taken from a single source, what makes the information identical to everybody. It also means a coherent and timely fusion of electronic and more traditionally-collected data (e.g., sale figures). While we devote the next section to the third goal, the fourth, the collaboration with partners, is probably the most evident. Retailer-supplier partnerships and relations with third-party logistics providers are among the most important types of collaborations in the electronic business environment.

III Global Optimization through Global Information

The availability of information to all partners in the supply chain allows companies to take better decisions, decisions that are timely, based on reliable information and, most important, taken from a global and not local viewpoint. If a department takes decisions on the basis of its own goals, it may completely miss the company objectives, even work against them. The minimization of the costs of a company is not necessarily reached through the minimization, for instance, of the transportation costs alone. Such local optimization would mean always using the cheapest, and typically slowest, transportation mean and serving customers with direct routes at low frequency. Only a holistic view of the entire system allows companies to reach their objectives. Internet-based information systems are the most powerful enabling mean to move from a sequential optimization toward a global optimization.

If a supply chain would be isolated from other supply chains, a global optimization would really be possible. The fact that most supply chains interact with other supply chains may create conflicts among different supply chains, make the optimization of a specific supply chain more difficult to attain, and force companies to find a compromise. In any case, the compromise should be found at the highest possible level and not where it is unnecessary. Moreover, appropriate operations research-based methodologies are required to evaluate the many possible strategies and trade-offs and select the most appropriate ones for the company objectives.

A management practice that has pushed companies to move from a local/sequential to a global optimization is the *Vendor-Managed Inventory* (*VMI*) policy. Consider a distribution system with a central warehouse from which products are shipped to retailers. With a VMI policy, the inventory of the retailers is controlled by the warehouse that organizes the deliveries in the globally most efficient way guaranteeing that no stock out will occur to any retailer. In a traditional distribution system, which we call *Retailer-Managed Inventory (RMI)* system, the retailers decide when and how much to order, and in most cases will use an order-up-to level policy. Then, the warehouse has to organize the distribution. The decisions of the warehouse are constrained by the decisions of the retailers and for this reason less cost-effective. In Bertazzi, Paletta, and Speranza (2006) the savings that can be obtained with the VMI policy are quantified. Both the VMI and the RMI systems are organized at best, that is in such a way that the total cost of each system, that includes fixed and variable production costs, fixed and variable transportation costs and inventory costs, is minimized. Such optimization is obtained by means of operations research methodology. It turns out that a VMI policy allows savings that range from 8% to 50%, depending on the specific situation. The savings are higher if the production costs are small and the prevalent part of the expense is in transportation, because the major factor of saving is in the transportation activities that benefit the most from the coordination. The savings might be obtained even without the adoption of a VMI policy but through a policy of partnership with the retailers oriented toward the global optimization of the system performance.

A major issue to consider in order to move from local/sequential to global optimization is the motivation for the partners to collaborate the corresponding distribution among partners of the savings coming for the global optimization.

IV. Electronic Business

The *electronic commerce* concept was introduced in the early 1990's and signaled the beginning of the commercialization of the Internet. E-commerce was essentially about transactions conducted between business partners to buy and sell goods and services. This definition is now considered as "old" and restrictive. The utilization of the *electronic business* term signals a holistic view of business using electronic means: buy and sell, serve customers, share knowledge, set up intra- and inter-organization communications, collaborate and, eventually, integrate vertically (e.g., suppliers and distribution channels) or horizontally (e.g., community-of-interest marketplaces) with business partners, and so on, for competitive advantage. Logistics and transportation are significantly impacted by this evolution.

The evolution of e-business has been strongly affected by the speculative stock-market bubble of the turn of the millennium, the "new economy" hype and the fall of the so-called dot.com companies. This negative impact seems to have been overcome, however. There is significantly less hype now, other emerging economic sectors capturing the attention of the media and the stock-exchange traders (the huge success of the Google public offerings not withstanding). Yet, the pace

of the penetration of electronic exchanges in business and society is accelerating and is becoming a fact of life.

IV.1. The Many Incarnations of Electronic Exchanges

There are several types and levels of electronic exchanges, often classified according to the nature of the transaction.

Business-to-Business (*B2B*) is what most people think of when the e-business topic is mentioned. It refers to electronic exchanges and transactions among firms and organizations, irrespective of the amplitude or scope of the transactions involved. B2B is the direct descendant of e-commerce and earlier EDI efforts. EDI is now, in fact, one of the many facets and instruments of B2B e-business. Yet, it is the Internet that provides the enabling support for B2B e-business as for the other facets of the electronic society. We take a closer look at B2B exchanges in Section IV.2.

Business-to-Customer (*B2C*) refers to relations between the firm and its customers. B2C e-business covers every type of activity the firms undertake to market and sell its products: passive websites describing the firm and its products, electronic broadcast of announcements and catalogs, interactive websites for direct sells to customers, individual e-messages to registered customers to maintain a high level of customer awareness relative to the firm, promote particular goods or services, or announce "new" and "spectacular" offers, and so on.

Firms at all levels of the digital scale, from "traditional" brick-and-mortar to "fully" virtual, engage in B2C activities. Almost all firms of the so-called developed world and many in the developing world implement web sites for promotion purposes. A continuously increasing number is also offering transaction capabilities that parallel or complement the traditional distribution channels, paper catalogs sent by slow mail, call centers for taking orders and customer support, phone solicitation, service counters, intermediaries (e.g., travel agencies), regular stores, etc. In this sense, one may qualify most brick-and-mortar firms as "click-and-mortar". Firms selling services or physical goods by electronic means exclusively have obviously developed their core business around the B2C concept. Virtual travel agencies (e.g., Expedia.com) belong to the first category, while firms such as Amazon.com that retail directly to customers from production or warehousing facilities illustrate the second.

In all cases, however, the design and operations of the physical logistic system is instrumental to the performance of the firm. With the exception of service-selling firms and of companies selling "virtual" products such as music, pictures, and software, all B2C activities involve the setup and operation of a distribution system. When regular or express carrier services are used to ship products to customers, the logistic system corresponds to a network of warehousing facilities, while the value-chain processes mainly address issues related to product procurement (selection of product providers, eventually), inventory management, and dispatch of product deliveries. In all other cases, routing issues have also to be addressed. As for regular operations of most firms, operations research methodology is at the core of the efficient and profitable logistics network setup and operation.

Electronic systems that provide services to individuals selling to organizations are identified as *Customer-to-Business* (*C2B*). Such services are not yet very much developed, however. Moreover, their impact on the logistics activities of the firm is limited. The impact on logistics of *Customer-to-Customer (C2C)* and *Government-to-Citizens* (*G2C*) electronic exchanges appears also rather limited but their role in the contemporary society is very important. C2C refers to all Inter-

net-enabled exchanges between private citizens: personal web sites, music and video exchanges, etc. In a broad sense, web sites that facilitate such exchanges belong to the C2C category, including for-profit organizations that, for example, manage auction sites dedicated to individual sellers and buyers (e.g., eBay). The G2C denomination encompasses all the electronic services that governments, at all levels, make available to the public, including commercial firms and not-for-profit organizations.

This very succinct overview of the various types of electronic exchange systems does not cover all aspects of the electronic society. The empowerment of the civil society, in particular through the proliferation of web sites representing non-governmental organizations, special interest groups, and discussion forums (the so-called blogs) is only partially covered by the types defined above. This empowerment may and does impact the policies of both governments and industry. Thus, for example, a location for a new plant may be abandoned due to pressure from special interest groups through electronic mailing and discussion groups. Hence, a number of additional factors have to be included in the decision process, particularly at the strategic level. On the other hand, this does not change the nature of the logistics planning and management processes and, thus, given the limited space available, we do not address this topic in this chapter.

IV.2 Business-to-Business Electronic Exchanges

B2B e-business may be further analyzed according to the scope of the exchanges: either centered on a specific company or on a group of firms that collaborate, compete or engage in both types of activities.

Most company-centric B2B activities concern the firm in relation with its suppliers or customers. The first case is identified as *many-to-one* B2B to reflect the flows of materials from many suppliers toward the firm and concerns the acquisition of materials and supplies. Traditionally, one differentiated between direct supplies for the core activities of the firm (e.g., production of the goods the firm sells) and other, so-called indirect, materials (e.g., supplies for the back-office), on the basis that the former requires long-term contracts directly and personally negotiated, while the latter may be decided on a case by case basis given current availabilities and prices. This differentiation persisted in the e-business era when the sourcing of direct materials was still deemed too strategic to be left to electronic negotiations and *e-procurement*, particularly on the spot market, was to be used for indirect materials only.

While not underestimating the value of direct negotiations and long-term contracts, one observes that this separation is fading away. Electronic markets are increasingly used to negotiate and acquire a wide gamut of supplies, materials, and services. Firms may negotiate on "open" electronic markets (e.g., the commodity markets) or implement private e-marketplaces where they usually control the negotiation processes and tools. The auctions by which many manufacturing and retail firms acquire long-term transportation services for their distribution routes illustrate the second case.

B2B communities of interest are bringing together the main participants to the value chain within particular industrial sectors (e.g., steel, automobiles, chemicals, etc.) to facilitate communications and exchanges, help discover potential suppliers or customers and build partnerships, enforce quality standards, and implement efficient electronic markets. The e-business environment and the Internet are fostering the co-operation between "small" firms for group purchasing of items of common interest. They are also significantly enlarging the economic field, facilitating the dis-

covery of potential partners in geographic zones not usually associated to one's own business practices.

On the sell side of B2B, one considers the firm in relation to its customers and is thus identified as *one-to-many* B2B. These relationships may take the form of B2C electronic marketing and selling activities, irrespective of the nature of the "customer", another firm or organization, one own distribution system or store, or an individual person. Such activities usually involve electronic markets as in the participation as seller to the communities of interest identified above.

One also identifies as B2B activities the coordination of the activities of the firm with those of its suppliers or customers. In a just-in-time environment, for example, one aims to coordinate its production, inventory, and distribution activities to the selling cycle and inventory management of its customers. These activities may also take place in a many-to-one environment where, for example, the arrival of supplies from various sources is made to match the production schedule. B2B coordination may also be enforced along the supply chain between a product provider, the transportation or distribution systems, and the final customer. Such *e-logistics* activities require advanced monitoring and information technologies and sophisticated operations research-based decision support systems.

Firms may also participate to many-to-many electronic exchanges. The above-mentioned communities of interest are an example of such activities; the participation to multi-lateral e-markets constitutes another. In multi-lateral electronic marketplaces, firms may be offering or acquiring goods or services. Some firms may do both. Many-to-many B2B may also be implemented within the organization, linking different departments, divisions, or participating firms. Private marketplaces to distribute tasks more efficiently constitute a prime example of such B2B activities.

Most B2B activities are performed as part of the value (supply) chain. They require an information exchange technology, as well as a number of modifications to the organizational structure and culture of the firm. They may also impact the actual procurement, production, and distribution activities and consequently the associated planning and operation processes. The development of models and methods to design and operate efficient e-logistic chains is still in its infancy but constitutes an exciting and challenging field for research and technological transfer.

Many B2B activities also involve participating to e-marketplaces and auctions. From the point of view of the market manager, be it the firm or a third party, the issue is what type of market to offer and how to design it. When one is only interested in buying or selling, the question is how to profitably participate to e-markets. We address these issues in the next section.

V. Electronic auctions

Marketplaces emerged early on in human history as physical locations (e.g., the village square) where goods could be sold, bought, or exchanged. In time, marketplaces have grown in scope, size, and sophistication, but their main goals still consist in discovering "partners" as well as negotiating the quantities to exchange and the corresponding prices. Electronic marketplaces are no exception. This section presents a brief description of e-markets following Crainic and Gendreau (2003).

In unilateral markets, one seller negotiates with several buyers, *one-to-many* markets, or, alternatively, one buyer deals with several sellers: the *many-to-one* case often encountered in firm procurement processes. Several buyers and sellers meet in *multi-lateral* markets. In such *many-to-many* settings, participants may be either buyers, or sellers, or both. Markets may be dedicated to

one product only or encompass negotiations on several commodities simultaneously (whatever the setting, several qualities or grades may be defined for each commodity). Moreover, products may be *indivisible* (e.g., a container) or *divisible* (e.g., telecommunication capacity) and may be traded one or several at a time. Markets aim to be efficient, either locally (i.e., maximize the benefit of the unique seller or buyer or the surplus of a many-to-many market) or socially (i.e., maximize the overall social welfare of the participants). In the case of freight transportation, the markets where regular distribution routes are auctioned off to carriers for a certain period of time (e.g., from one to three years) belong to the one-to-many case, where the commodities (routes) may be either considered indivisible (service for the whole volume on a route is sold to one carrier only) or divisible (several carriers may serve the same route). Freight exchanges where loads (e.g., containers or full truck loads) of different shippers are offered to several carriers may be described as many-to-many, multi-commodity, indivisible markets.

Auctions constitute a broad and important class of market organization that involves a formal design and negotiation process (Abrache, Crainic, and Gendreau, 2004; Caplice and Sheffi, 2003; Pekeč and Rothkopf, 2003; Rothkopf and Park, 2001; Sheffi, 2004). Participants to an auction declare bids, that is, they indicate the quantities they are ready to buy, sell, or exchange, as well as the corresponding prices (several other conditions, such as technological or product quality restrictions, on the objects or services traded are usually part of the bid as well). Several participants will generally declare bids on the same object or group of objects. The auctioneer receives the bids and ensures that the negotiations proceed efficiently and fairly, according to the rules of the market. In particular, it verifies the legality of the bids and determines, through an allocation mechanism, which one among the conflicting bids wins (who gets what and how much) and at what price. Markets are said to be optimized when an optimization formulation and method is used as allocation mechanism.

Assuming bids include the true valuations of participants for the objects or services on the market, a simple and direct market mechanism would be: "Description of items on the market; call for proposals; submission of bids by participants; winner determination through the allocation mechanism; announcement of winners and implementation of the deals". There are very few (if any) opportunities to implement such an ideal mechanism. The primary cause lies with the lack of information available to the auctioneer regarding the true intentions, possibilities, and limits of participants and, in particular, their true valuations of the items on the market. Participants are generally reluctant to disclose such information, even to a "neutral" agent under secrecy commitments, because it includes proprietary data on the economics and processes of the firm. Moreover, such data may not even be completely available to the firm. Thus, for example, the "true" valuation of an item often becomes clear only during the negotiation according to the other items that are on the market or have been acquired.

Approximate market mechanisms are therefore the norm. One of the most widely used, particularly when public institutions and governments are involved, are the so-called closed-envelope mechanisms where participants bid once and the auctioneer selects winners based on these proposals. "Lowest (or highest, as the situation commands) bid wins" is the usual selection criterion, with consideration given to characteristics such as product quality or participant reliability to perform the service. It is known, however, that this mechanism does not offer any guarantee of efficiency and that, in fact, it often yields inefficient allocations. Second-price criteria, where the highest bidder wins but pays the second highest price (the so-called Vickrey-Clarke-Groves auctions), have been extensively studied, since they present the advantage of inciting participants to bid truthfully,

but little used because they are open to manipulations by participants (signaling and collusion, for example).

Multi-round mechanisms are increasingly proposed to address these shortcomings. Multi-round markets attempt to bring participants to progressively "reveal" their true intentions and valuations and, thus, to achieve the best allocation possible. In such a setting, participants make initial bids and the auctioneer determines a temporary allocation and prices. The auctioneer returns this information to participants (according to pre-determined privacy rules), which may then modify their bids (in quantity, value, composition, etc.) or submit new ones. Pre-determined rules guide the definition and modification of bids, pace the auction, and determine its end.

To illustrate, consider a periodic multi-lateral market for geographically dispersed heterogeneous commodities (e.g., natural resources) where buyers express technological requirements on the mix of goods they purchase (Bourbeau *et al.*, 2005). The market opens up periodically (e.g., once a day, once a week) and the agents in the corresponding economic sector negotiate using the centralized and optimized market. All possible multi-lateral trades are thus solved simultaneously. Commodities are classified by type or quality. Sellers may offer several commodity types separately or mixed up in lots. Buyers need to combine different grades and qualities, while technological constraints limit the quantities of each type of commodity they may acquire. Transportation costs are significant. The objective of this type of markets is to explicitly optimize both the production and transportation of resources in the industry.

Let K be the set of products. The definition of a product is domain specific. Generally speaking, however, a product is a generic classification reference, such as a quality of ore, a wood species, a type of grain, etc. It is a commodity differentiated by type and quality. Products are combined in lots that sellers and buyers may trade. To simplify the presentation (but with no loss of generality), a lot is sold by one and only one seller, is attached to a specific location and has its own idiosyncratic quality. Since a producer may sell more than one lot, the number of lots may exceed the number of producers. More importantly, a lot has its own composition of various products (e.g., oil or ore grade). Let $b(k,l)$ denote the proportion of product k in lot l, where $\sum_k b(l,k) = 1$. A maximum quantity Q^l is available for lot l. Lots are to be acquired by buyers grouped in set J. Buyers face technological constraints and use proprietary recipes and, thus, desire to acquire particular mixes of products. Given the diversity in product characteristics displayed by the lots on sale, buyers express preferences for the various lots by specifying two quality adjustment coefficients, one multiplicative, $r(j,l)$, and one additive, $s(j,l)$, which indicate that for buyer j one unit of lot l is equivalent to $r(j,l)$ units of a standard lot and is worth $s(j,l)$ monetary units more than a standard unit. Let $M(j,k)$ and $m(j,k)$ denote the maximum and minimum proportions, respectively, of product k that buyer j is ready to accept in the mix it purchases, while Q^j indicates the maximum total quantity of all products buyer j requires. Unit transportation costs between the seller of lot l and buyer j are denoted $t(j,l)$.

At the core of the market lies a *market-clearing mechanism*: a formal procedure that determines the "optimal" *allocation, who sells what (how much) to whom and at what price*, of goods given the participants and the market state. Assuming buyers and producers are willing to reveal information to the market, participants are asked to communicate their preferences, that is, their production cost or utility functions (their willingness to pay), together with all relevant technical information: transportation costs, technical constraints, etc. Denote by $U_j(\cdot)$ the utility function of buyer j and by $C_l(\cdot)$ the cost or production function of lot l. The decision variables of the optimized

multi-lateral allocation mechanism, $q(j,l)$, indicate how much each buyer j buys of lot l. The corresponding optimization formulation is

$$\text{Maximize } \sum_j U_j\left(\sum_l r(j,l)\, q(j,l)\right) - \sum_l C_l\left(\sum_j q(j,l)\right) - \sum_j \sum_l \left(t(j,l) - s(j,l)\right) q(j,l)$$

$$\text{Subject to } \sum_l q(j,l) \le Q^j \quad \text{for all buyers } j$$

$$\sum_j r(j,l)\, q(j,l) \le Q^l \quad \text{for all lots } l$$

$$\sum_l b(k,l)\, r(j,l)\, q(j,l) \le M(j,k) \sum_l r(j,l)\, q(j,l) \quad \text{for all buyers } j \text{ and products } k$$

$$\sum_l b(k,l)\, r(j,l)\, q(j,l) \ge m(j,k) \sum_l r(j,l)\, q(j,l) \quad \text{for all buyers } j \text{ and products } k$$

$$q(j,l) \ge 0 \quad \text{for all buyers } j \text{ and lots } l$$

The market maximizes buyer surplus minus the production and transportation costs subject to all technological constraints. Under classical, but strong, economic theory hypotheses, buyer utility functions are assumed concave (continuous, piece-wise linear, and strictly decreasing marginal buyer benefit, while costs are assumed convex (continuous, piece-wise linear, and strictly increasing marginal cost of producing a given lot). Using standard optimization methodology, the allocation mechanism yields prices and quantities that equilibrate supply and demand and that are the solution (dual and primal) of an optimization (maximization) formulation. It is unlikely, however, that such a mechanism will operate ever mainly due to the unwillingness of participants to disclose all their data, especially full supply and demand functions (assuming buyers and sellers do know these data) to even the most secure auctioning system. Multi-round auction mechanisms are therefore proposed in most such cases.

In many markets there is the need to negotiate items in bundles: allocation of airport take-off and landing time slots, wireless communications spectrum licenses, distribution routes, commodities for specific production recipes, loads to form closed (i.e., returning at the origin depot) multi-stop routes, assets in financial markets, supply chain formation and coordination, and so on. All these cases have one thing in common: they all trade items of different nature that are interrelated from the perspective of the participants: the value of one item to a participant depends whether or not the participant managed to obtain (or sell) a number of other items. For example, the value of a load to a carrier will depend on whether or not one or several other loads may be secured to ensure a round trip may be constructed such that the vehicle is "always" moving loaded. Items may be complementary or substitutable. More precisely, if A and B are two items and $v(\cdot)$ denotes the evaluation function of the participant, A and B are said to be complementary if $v(A,B) > v(A) + v(B)$, and substitutable if $v(A,B) < v(A) + v(B)$. Loads in the previous example are complementary. Several loads that are available at about the same time, between the same pair of cities, are substitutable. Abrache, Crainic, and Gendreau, 2004; Pekeč and Rothkopf, 2003; Rothkopf and Park, 2001; De Vries and Vohra, 2003 review issues and contributions related to combinatorial markets.

Combinatorial auctions refer to marketplaces in which participants are allowed to bid on combinations, or bundles of items, and are increasingly considered as an alternative to simultaneous single-item auctions. Being able to bid on bundles clearly mitigates the exposure problem, since it gives the participants the option to bid their precise valuations for any collection of items they desire. On the other hand, combinatorial auctions often require the market maker and the participants to solve complex decision problems.

To illustrate, consider a simple combinatorial auction where a firm "sells" m different (indivisible) distribution routes, represented by set G, to n potential buyers (carriers), which are allowed

to submit sealed bids on bundles of routes. A bid made by buyer j, $1 \leq j \leq n$, is defined as a tuple (S, $p(j,S)$) where S is a subset of routes in G and $p(j,S)$ is the amount of money buyer j is ready to pay to obtain bundle S. If route i is in bundle S, $\delta(i,S)$ is equal to 1 and is 0 otherwise. Define $x(j,S) = 1$ if S is allocated to buyer j, and 0 otherwise. The auctioneer must decide which bids win and which ones lose, under the condition that no single route is allocated to more than one carrier, and such that its revenue from the sale of the right to service the routes is maximized. The winner determination problem can be formulated as follows:

$$\text{Maximize } \sum_j \sum_{S \subseteq G} p(j,S)\, x(j,S)$$

$$\text{Subject to } \sum_j \sum_{S \subseteq G} \delta(i,S)\, x(j,S) \leq 1 \text{ for all routes } i \text{ in } G$$

$$\sum_{S \subseteq G} x(j,S) \leq 1 \text{ for all carriers } j,\ 1 \leq j \leq n$$

$$x(j,S) \in \{0,1\} \text{ for all bundles } S \subseteq G, \text{ or all carriers } j,\ 1 \leq j \leq n$$

The formulation is a weighted set packing problem (De Vries and Vohra, 2003). Similarly to most combinatorial markets, this winner determination problem is NP-hard (Rothkopf, Pekec, and Harstad, 1998), the number of possible bids growing exponentially with the number of routes on the market, and straightforward solution approaches do not work in most actual settings. Significant research is thus dedicated to combinatorial auction mechanism design issues, as well as to the associated operations research and combinatorial optimization methodologies. These efforts have already resulted in the successful utilization of combinatorial auctions to many applications. In the case of freight transportation, combinatorial auctions appear as powerful mechanisms to auction the right to service regular distribution routes and to design freight exchanges where many shippers and carriers meet to determine who will move the loads on the market and at what price.

Participants to combinatorial auctions face serious challenges, however, and research efforts start to be dedicated to this topic. The first and foremost challenge faced by participants in electronic auctions is clearly to identify which items are of interest to them and acceptable price ranges for these items. This is obviously further compounded in the case of combinatorial auctions by the need to build attractive bundles and to price them.

A major issue to be addressed by participants when there are significant value interactions is that of exposure risk. Exposure basically occurs when a participant is successful in obtaining only part of a bundle of complementary items it is interested in; more precisely, there is exposure when a participant obtains part of a bundle at a price that is higher than its value to him, but is not guaranteed to obtain the remainder of that bundle. Obviously, such a situation will be encountered when participants try to obtain items on different markets or when markets do not allow for combinatorial bidding. Thus, for example, a carrier may identify loads that would make a closed "full" route on the different markets set up in the regions visited. These loads are still complementary for the carrier, but it is impossible to negotiate them together. A similar situation can occur when participants bid simultaneously in parallel auctions for items that display significant substitution effects. An extreme case is the situation where a participant is interested in a single item among a collection of items (e.g., loads or routes) that are auctioned off simultaneously. Should the participant bid too aggressively, it may very well end up clinching two or more of these items. On the other hand, if the participant is too timid in its bidding, it may end up with none of the items.

The two previous situations highlight the need for participants to develop appropriate bidding strategies in relationship with their needs and their tolerance to risk. These strategies must also account for the presence of competitors on the markets: both the number of these competitors (or a

reasonable estimate of it) and their bidding behavior are key elements in this assessment. It must be stressed, once again, that the nature and number of markets a participant is involved in have a dramatic impact on the type of strategy a participant needs to develop. For instance, it is much easier for a participant to develop an effective strategy for obtaining a bundle of complementary items if all these items are traded on a single marketplace that allows combinatorial bidding.

Advisors may be defined as specialized decision-support software specifically designed to support participants in the complicated negotiation processes involved in the most sophisticated electronic markets, such as simultaneous auctions for several goods, sequences of sequential auctions or combinatorial auctions. Advisors may have several functions, according to the degree of sophistication of the firm in relation to Internet and the cyberspace: identify promising marketplaces and loads, assess the competition, build and price bids, determine a bidding strategy, develop contingency plans in case one ends up losing on loads that had been identified as attractive, conduct the negotiation, close the deal, etc. For most of these functions, the associated models and methods are encapsulated into software agents that help automate the negotiation process. See Crainic and Gendreau (2003) for a more in-depth discussion of this issue.

VI Case example: FreightMatrix.com

FreightMatrix is an e-marketplace that supports shippers and carriers with the objective of providing services and optimizing costs and profits.

The web site FreightMatrix.com has been created by i2 Technologies, a company leader in the production of software for logistics and supply chain management. FreightMatrix.com has two sections: FMX private marketplace and FMX public marketplace.

FMX private marketplace is designed for the customers that intend to create their own web site and are interested to have a secure access to a number of logistic services. Large and mid-size shippers, 3PLs, and exchanges use FMX private marketplace to on-line manage their own supply chain or the supply chain of their customers. The services offered by the private marketplace are of operational, tactical, and strategic nature. Among the operational and execution services: Shipment optimization, Shipment execution, Freight matching, Tariff management, Parcel & small package management, Intelligent messaging and monitoring. For example, Freight matching provides producers, distributors, and 3PLs with a tool to quickly and simply buy transportation for loads on a spot basis. Moreover, it allows carriers to identify demands for transportation of loads and improve the vehicles utilization rate. Parcel management can be integrated with existing systems, gives access to information in real time, and reduces errors and costs. Among the tactical planning services we find: Rate quotation, Transportation planning, Transportation Bid Request (more about this service later), Export trade compliance and among the strategic planning services: Transportation Bid Collaboration (more about this service later) and Network planning & optimization. The latter is a tool that supports location decisions, allowing the decision makers to evaluate cost trade-offs.

The advantages for the customers of FMX private marketplace are the use of high quality software; complete saving of the costs for the private hosting, software and maintenance; a variety of services; and the possibility of connection in a secure environment, easily accessible to all partners of the supply chain. FMX public marketplace is mostly of interest to carriers and small shippers. Several of the tools made available through the private marketplace are available here too, sometimes in a simplified form.

Two possibilities are offered by the FMX marketplace to shippers to get transportation services: Transportation Bid Request (TBR) and Transportation Bid Collaboration (TBC). Both services are available in the private and in the public marketplace. TBR is a short period tool aimed at providing a quick answer to a transportation demand. Demands are posted individually or in groups. Carriers access this service and pick up the demands that best fit into their plans.

TBC is a more complex auction mechanism to manage long term contracts. The basic structure of the auction is as follows. Shippers auction all or a major part of their network of routes. Then, carriers provide their offers on the auctioned routes. TBC optimizes the system by finding the cheapest assignment of offers to transportation demands. In Figure 1 the auction process is depicted. Three basic steps are shown: Shipper Bid Support (SBS), the tool to create the shipper network, Carrier Bid Response (CBR), the tool used by carriers to submit their offers and Carrier Bid Optimizer (CBO), the tool used to optimize the offers and conduct What-if analysis. After the data have been imported from the database into SBS, the shipper creates its sets of routes, possibly combining routes in groups, and posts the sets on the web from which carriers download them to later insert their offers. The carriers usually have one week to prepare their bids. Then, the shippers may update their demands and, finally, routes and offers are taken from SBS and optimized by CBO. After the optimization took place, the shipper may negotiate the contracts with the carriers or conduct another round. In such a case the process is repeated.

SBS deals with one shipper at a time. The shipper auctions its routes to several carriers. The only way for carriers to bid on sets of routes of different shippers is that a 3PL or a consortium presents the sets. Each route is represented as an Origin-Destination pair. The shipper can define requirements on a route, for instance that the route has a stop in between, that there are two drivers (for long routes), that the load be shipped within 24 hours. Moreover, for each route the distribution of the demand over time must be provided. The shipper may invite any set of carriers to bid. CBR is the software used by carriers to create their offers. Three types of offers are possible: the single bids, the combo bids and the reserve bids. If the shipper has chosen the "partial bidding" option, the carriers have the possibility to submit, for each route, an offer for a demand lower than that required by the shipper. CBO in this case may assign the route to more than one carrier. The single bids represent the traditional way to submit bids. The price offered by a carrier for a route is the price per mile multiplied by the distance and the number of trips plus a team charge, in case two drivers are required. A combo bid is a bid submitted on a set of routes. In this case, the price for the individual routes may be different from each other. To clarify the complexity of creating bids for carriers, consider the following example. A set of routes A, B, and C with demands 125, 99, 1200 (total demand 1424) is posted together with other sets of routes D and E with demands 500 and 750 (total demand 1250). If a carrier is interested to any of the two but not to both he can make a combo bid on the two sets and set a limit on the possibility to cover the demand equal to 1424. The reserve bid allows a carrier to set a price for ranges of demand. If a carrier offers a reserve bid for a certain amount of demand, the price holds for any lower demand. Take the following example. A route has demand 200. Carrier A submits a single bid with price 1.25$ for a demand equal to 100. A carrier B submits a combo bid with price 1.21$ for a demand equal to 175. In this case, the route is not covered by any bid. If a carrier F submits a reserve bid for 1.28$, then the route will be assigned to carriers B (for a demand equal to 175) and F (for a demand equal to 25). CBO optimizes the offers by assigning the routes to the bids in such a way that the total cost is minimized. A route may happen not to be covered by any bid for any of the following reasons: no carrier submits a bid that includes the route, the price offered by the carriers is higher than the maximum set by the shipper, the carriers cover only part of the demand. Since more rounds are possible, it may happen that a route is not

covered in a first round but is covered in a successive round. It is possible for a shipper to ensure that a reliable carrier gets a minimum amount of work or that an unreliable carrier is penalized.

CBO can also be used to conduct what-if analyses. A typical use for the shipper is to see what changes if the expense of a carrier is limited to a lower bound or an upper bound or if the number of loads assigned to a carrier is limited. Changes in the prices can be tested as well. If more rounds are required the whole process would be repeated. The carriers can see the routes assigned to them and modify the bids. A carrier cannot see the routes assigned to other carriers. There is no limit in the number of rounds that a shipper can conduct. However, the average number of rounds is 2 and it has been seen that the best results are obtained with 2 to 4 rounds. A typical engagement lasts from few weeks to several months.

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